Implications of Channel Incision for Tuolumne Meadows Restoration

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Photo taken Vivian Sieu, 2018

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Introduction

Tuolumne Meadows is a dynamic alpine wetland formed by several glaciation events in the Sierra Nevada. These meadows are comprised of histosols and several kinds of fluvial entisols, distinguished from most other Sierra soils of Yosemite National Park by their strong hydric characteristics, high water holding capacity, and rich organic matter (Moore et al., 2013; Ratliff, 1985). These soils were created by seasonal flooding and maintained by densely rooted vegetation that excludes tree establishment and recruitment (Loheide II et al., 2009). Furthermore, the hydric properties and high organic matter content of soils in this meadow greatly extend growing degree days (GDD) of plants by prolonging moisture retention that would have been lost to drainage or evaporation. Because of these unique features, Tuolumne Meadows supports a variety of species that utilize the forage, water availability, and open space of this ecosystem such as deer, raptors, and many kinds of invertebrates. Tuolumne Meadows supports specific species that rely heavily on edge interactions between wetland habitat and conifer forest, including the threatened Dusky Flycatcher and Yosemite Toad. (Herbst and Cooper, 2010; Loffland et al., 2013; Roche et al., 2012).

However, strong anthropogenic factors have threatened the integrity of this ecosystem since the presence of sheep grazers in Yosemite. Historic overgrazing by sheep and shifting hydrologic regimes due to climate change have disrupted the feedback loops that maintain Tuolumne Meadows and allow it to act as a carbon sink (Roche et al., 2012; Wolf, 2017). These disrupting influences enable erosive processes that threaten meadow habitat through channel incision and gullying (Ratliff, 1985).

Though restoration efforts are currently underway focusing on vegetative cover, Tuolumne Meadows may face further degradation from channel incision created by high flows resulting from higher volumes of precipitation runoff (Herbst and Cooper, 2011; Lord et al., 2011). Channel incision has been shown to reduce the relative abundance of hydrophytes and facilitate lowering of the water table up to 30 meters away from the stream bank in meadows, resulting in conversion of the system from a wetland into a drier habitat (Lord et al., 2011; Schilling et al., 2004). The rate and extent of channel incision varies based on multiple abiotic, biotic, and climatic factors. The legacy effects of extensive sheep grazing throughout the late 1800s and early 1900s, as well as the effects of gully erosion, fire suppression, and lodgepole pine encroachment continue to degrade Tuolumne Meadows and reduce their capacity for resilience (Ratliff, 1985). The following research paper argues that montane meadow conservation is necessary to attain the benefits of specific hydrogeomorphic processes and biodiversity ecosystem services found in Tuolumne Meadows.

Methods

Repeat channel morphology data were collected in June of 2015 and 2018 along two reaches of the Tuolumne River in Tuolumne Meadows. These data represent channel bed morphology following a long drought (2012-2016), and two years of historically high precipitation (2017-2018), with 2017 having the highest total precipitation and snow water equivalent (SWE) on record since 1983 (California Water Science Center, 2018; Osborne et al., 2017). Study reaches were chosen based on how representative they were of the entire river reach, typically containing at least one riffle, run, and pool.

Bank-full cross-sectional data were taken at each reach, including left edge of water (LEW), right edge of water (REW), left bank (LB), right bank (RB), and channel depth. Channel transects were defined by width measurements taken with a standard 100-meter transect tape. Channel profiles were obtained by using a survey grade auto level instrument to measure elevations at intervals along each transect. Data were standardized according to the USGS NAWQA stream characterization protocol (Faith *et al.* 1998).

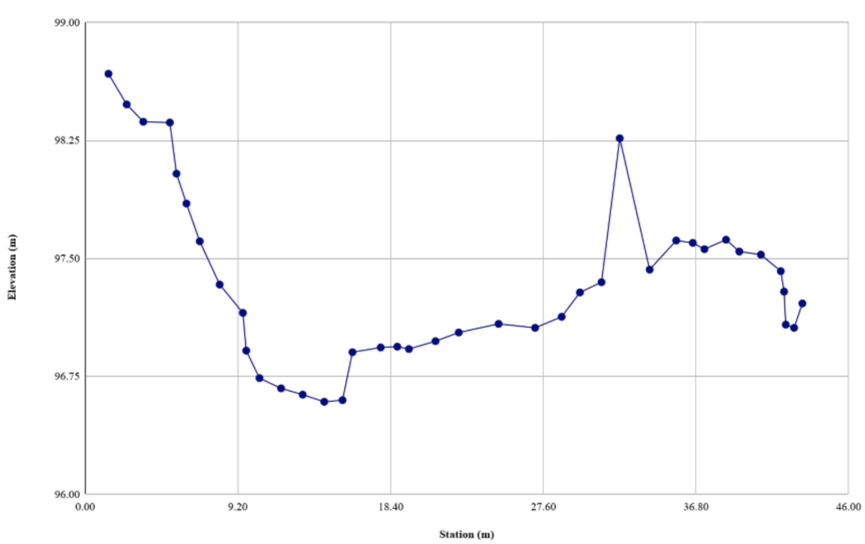
Lastly, the data were analyzed to determine changes in channel depth and width between 2015 and 2018. GPS points were used to confirm identical cross section lcoations for both years, and all measurements were taken in June. Channel width was determined from the top of the floodplain/meadow surface on each bank. Maximum channel depth was determined by subtracting the elevation of the deepest point from the floodplain surface. Total change between 2015 and 2018 channel width and depth was compared for each of the two surveyed reaches.

Results

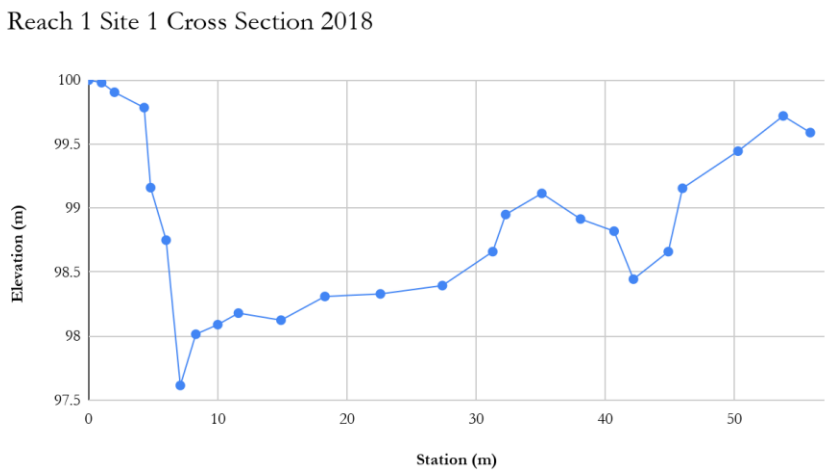
Graphic representations of stream cross sections and numerical values of channel width and depth were used to compare reaches from 2015 to 2018. Graphs 1 to 4 show an overall trend of channel widening, but not of significant deepening. As seen in table 1 and 2, depth measurements taken at reach 1 and 2 show that depth slightly decreased in 2018 compared to 2015; however, at both reaches, the channel width measurements increased by several meters. Graph 6 shows the total change in discharge between 2015 and 2018 (data collected at the time of surveys in June 2015 and June 2018), with 2018 having significantly higher flow values in June. Precipitation trends are shown in Graph 7 (data from station ID KCAYOSEM21), which depict heavy precipitation events in 2017 & 2018, likely contributing to higher flows.

<u>Graph 1</u>

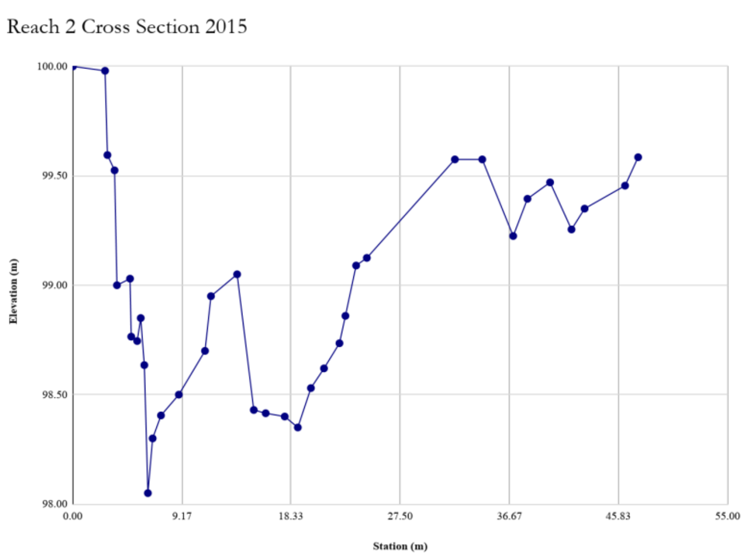
Reach 1 Site 1 Cross Section 2015



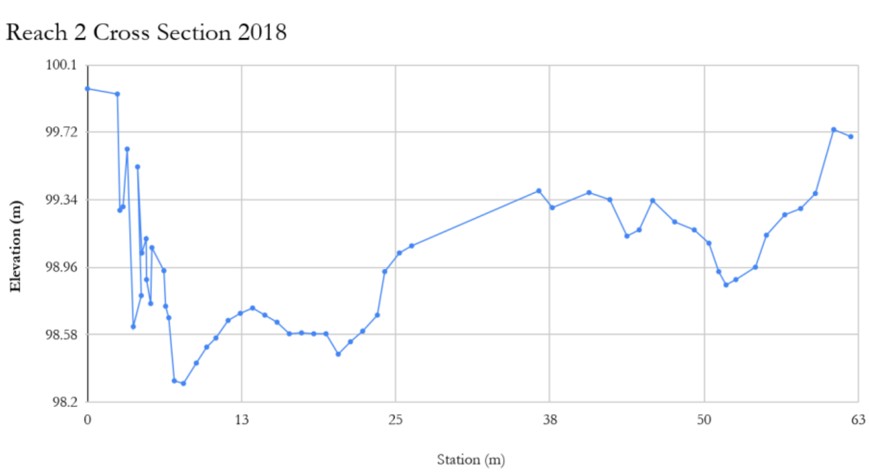
Graph 2



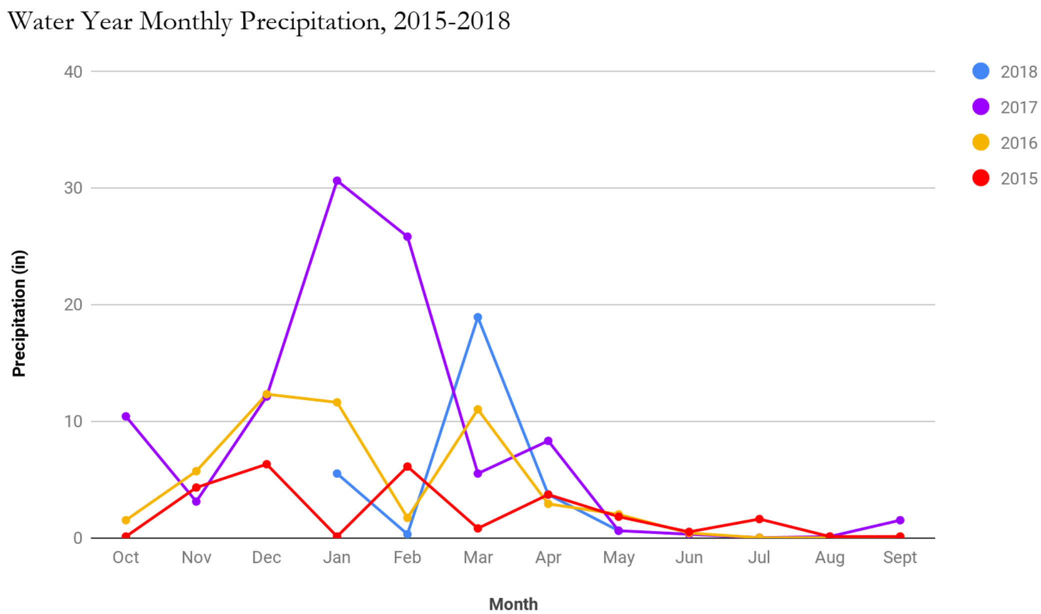
Graph 3



Graph 4



Graph 6



Graph 7

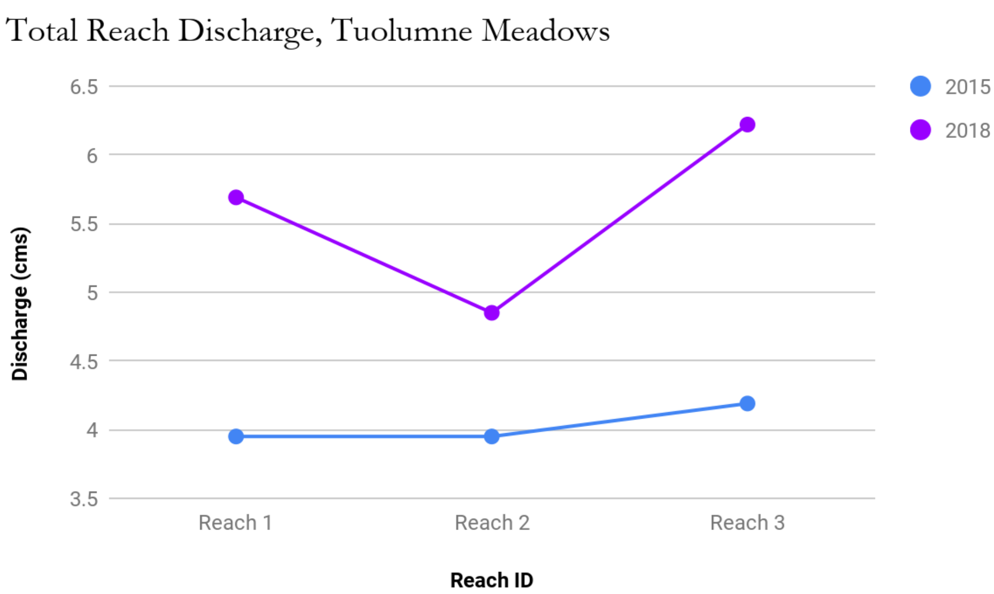


Table 1. Change in Channel Width

Reach #	Stream Channel Width 2015 (m)	Stream Channel Width 2018 (m)	Change Over Time (m)
1	27.1	30.8	+3.7
2	28.6	32.8	+4.2

Table 2. Change in Channel Depth (AVG)

Reach #	Max Channel Depth 2015 (m)	Max Channel Depth 2018 (m)	Change Over Time (m)
1	2.110	2.350	-0.24
2	1.950	1.775	-0.175

Image 1 – Reach 2

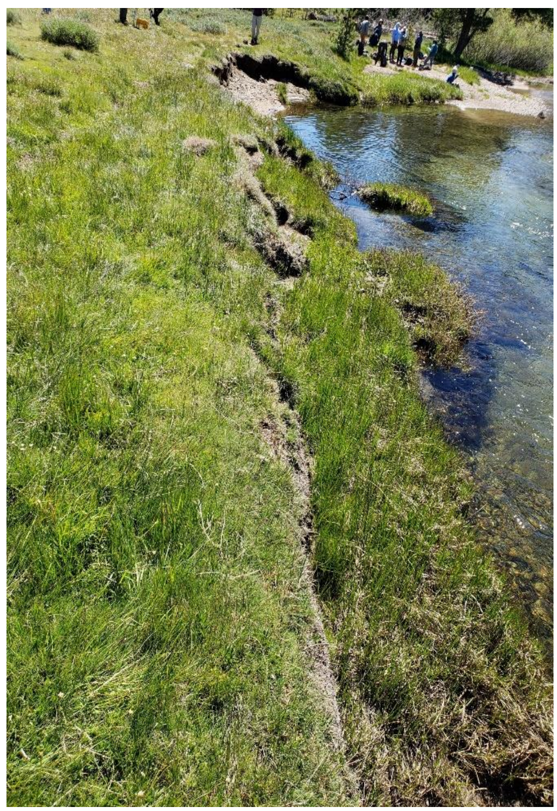


Image 2 – Reach 1

Image 1 and 2 show erosion of the riverbank in Upper and Lower Tuolumne Meadows survey sites in 2018. Channel erosion seen here is likely a result of natural channel meandering which is regulated by riparian vegetation types and discharge volume.

Image 3

Image 4

Images 3 and 4 show conifer encroachment, namely Lodgepole Pine, in Upper and Lower Tuolumne Meadows. Overgrazing and fire suppression in the late 19th and early 20th century reduced the abundance of this meadow's historical species of grasses and sedges.

Discussion

The findings of this study show an increase in channel width in some channel locations in Tuolumne Meadows between 2015 and 2018, indicating that the channel is erodible and able to meander. Images 1 and 2 show recently eroded banks, but the lack of channel increases in depth indicate the channel's ability to shift laterally without also experiencing significant vertical channel incision.

Tuolumne Meadows is likely experiencing lateral channel migration due to the erodibility of meadow soils but stability of the downstream granodiorite bedrock end of the meadow. The bedrock essentially creates a low 'dam' preventing further vertical incision. The loss of the meadow's traditional deep rooting biomass from grazing significantly affected soil stability, which can lead to a greater extent of meandering in the future (Wolf, 2017). High precipitation events, like those of the 2017 water year, are expected to be more frequent with increased climate warming, and will need to be considered in future restoration efforts (Dettinger et al., 2011; Kapnick and Hall, 2012).

Conclusion

The extreme high flows of 2017 provided a unique opportunity to observe the effects of increased precipitation and high flow on channel morphology. Our data suggest the Tuolumne River stream channel widened in some locations without increasing channel depth, suggesting lateral migration of the channel. The meadow stream reaches should continue to be monitored to track channel morphology and the response of surrounding biotic communities. Further studies should examine how current restoration efforts in Tuolumne Meadows are affected by sudden, shifts in the stream channel. Tuolumne Meadows is predicted to be a future climate refugia, but consistent and effective adaptive management efforts that account for evolving channel morphology are unquestionably necessary to ensure the long-term resilience of Tuolumne Meadows.

Sources

California Water Science Center (2018). *2012-2016 California Drought: Historical Perspective*. U.S. Geological Survey.

Dettinger M (2011). Climate change, atmospheric rivers, and floods in California -- A multimodel analysis of storm frequency and magnitude changes. *Journal of the American Water Resources Association*, 47(3): 514-523.

Faith, Fitzpatrick et al. 1998. "Revised Methods for Characterizing Stream Habitat in the National Water-Quality Assessment Program U.S. Geological Survey." *Environmental Protection* 98:67.

Florsheim J. Chapter 3: Fluvial Processes and Morphology Assessment. In: California Watershed Assessment Manual Volume II. [Draft]

Herbst DB and Cooper SD (2010). Before and after the deluge: rain-on-snow flooding effects on aquatic invertebrate communities of small streams in the Sierra Nevada, California. *Journal of the North American Benthological Society*, 29(4): 1354-1366

Kalff, Jacob. 2001. "Limnology."

Kapnick S and Hall A (2011). Causes of recent changes in western North America snowpack. *Climate Dynamics*, 38(9):1885-1899.

Loheide II SP, Deitchman RS, Cooper DJ, Wolf EC, Hammersmark CT, and Lundquist JD (2009). A framework for understanding the hydroecology of impacted wet meadows in the Sierra Nevada and Cascade Ranges, California, USA. *Hydrogeology*, 17(1): 229-246.

Lorde ML, Jewett DG, Miller JR, Germanoski D, and Chambers JC (2011). Chapter 4: Hydrologic processes influencing meadow ecosystems. In: Chambers, Jeanne C.; Miller, Jerry R., eds. Geomorphology, hydrology, and ecology of Great Basin meadow complexes - implications for management and restoration. General Technical Report RMRS-GTR-258. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. p. 44-67.

Miller JR, Lord ML, and Germanoski D (2011). Chapter 5: Meadow sensitivity to natural and anthropogenic disturbance. In: Chambers, Jeanne C.; Miller, Jerry R., eds. Geomorphology, hydrology, and ecology of Great Basin meadow complexes - implications for management and restoration. General Technical Report RMRS-GTR-258. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. p. 68-84.

Moore PE, Wagtendonk JWv, Yee JL, McClaran MP, Cole DN, McDougald NK, and Brooks ML (2013). Net primary productivity of subalpine meadows in Yosemite National Park in relation to climate variability. *Western North American Naturalist*, 73(4): 409-418.

Osborne H, Lerman K, and Kozlowski D (2017). *California and Northern Nevada Series of Significant Precipitation Events*. California Nevada River Forecast Center.

Ratliff RD. Meadows in the Sierra Nevada of California: state of knowledge. General Technical Report PSW-84. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1985. 52 p.

Wolf EC (2017). *Ecosystem Function, Degradation, and Restoration in Wetlands of the Sierra Nevada, California* (Doctoral Dissertation).

Schuurman GW (2018). Projected avifaunal responses to climate change across the U.S. National Park System. PLoS ONE, 13(3): e0190557.

Yarnell SM, Petts GE, Schmidt JC, Whipple AA, Beller EE, Dahm CN, Goodwin P, and Viers JH (2015). Functional flows in modified riverscapes: hydrographs, habitats, and opportunities. *Bioscience*, 65(10): 963-972.